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MEASUREMENT OF AIR TEMPERATURE  
FLUCTUATIONS WITH THERMOCOUPLES

By

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## ABSTRACT

Equations for determining the radiant heating and time constant of small thermocouples used for air temperature measurement are presented. Calculated and measured values are compared for 0.0025, 0.0127, and 0.0508 cm diameter copper-constantan thermocouples exposed to direct sunlight. The largest thermocouple gives measured temperatures that are approximately 1.3°C higher than air temperature, and the smallest thermocouple reads about 0.3°C above air temperature when they are exposed to direct solar radiation. In direct sunlight and for a range of wind speed of 100 to 500 cm sec<sup>-1</sup> the temperature is reduced by 0.8 and 0.1°C for the largest and smallest thermocouples, respectively.

The effects of two types of aspirated thermoshields on temperature fluctuations measured inside the shield with the 0.0025 cm thermocouples were determined. Thermoshield design was shown to be critical in temperature fluctuation measurement.

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## INTRODUCTION

Fine-wire thermocouples have been used for measuring air temperature fluctuations in a number of studies. In some studies (e.g., House, et al., 1960) it is assumed that radiant heating errors on very small thermocouples are negligible. However, Swinbank (1951) calculates that the mean temperature measured by a 0.0025 cm diameter thermocouple exposed to direct sunlight could be 0.13°C too high when the wind speed is 200 cm sec<sup>-1</sup>. An objective of this study was to measure radiant heating errors for several sizes of thermocouple and compare the values obtained with calculated values.

Since fine-wire thermocouples are used for measuring air temperature fluctuations, it would be helpful to be able to calculate time constants for thermocouples of various sizes in terms of wind speed and wire diameter. Also, if the thermocouples are used inside aspirated radiation shields in order to make accurate mean temperature measurements, one should know what effect, if any, aspiration has on the measurement of temperature fluctuations. A further objective of this study, therefore, was to compare experimentally determined time constants with values calculated from heat transfer equations and to determine the effects of aspiration on measured temperature fluctuations.

## RADIANT HEATING EFFECTS

The temperature of a thermocouple is determined by the rates of convective and radiative heat transfer at its surface. Ideally, the convective heat transfer should be much larger than the radiative heat transfer so that the thermocouple temperature accurately represents air temperature. To determine the error in air temperature measurement due to radiation, the energy balance for a thermocouple (similar to development by Gates, 1965) can be written in terms of  $\Delta T$ , the difference between thermocouple and air temperatures. If the thermocouple is assumed to be a horizontally oriented, infinite cylinder with the top half radiating to the sky and the bottom half radiating to the ground, then

$$\Delta T = \frac{\epsilon_s (1 + \frac{\pi\alpha}{2}) R_s + \pi\epsilon_L (\frac{R_a + R_g}{2} - \sigma T^4)}{h} \quad (1)$$

where  $h$  is the average convective conductance,  $\epsilon_s$  and  $\epsilon_L$  are short- and long-wave emissivities of the thermocouple,  $\alpha$  is the albedo,  $R_s$  is the short-wave incoming radiation,  $R_g$  is the long-wave radiation from the ground,  $R_a$  is the long-wave atmospheric radiation,

$\sigma$  is the Stephan-Boltzmann constant, and  $T$  is the thermocouple temperature.

Average convective conductance for infinite cylinders in forced convection can be approximated (Kreith, 1965, p. 411) by

$$h = \frac{Kk}{D} \left( \frac{V D}{v} \right)^n \quad (2)$$

where  $D$  is the wire diameter,  $V$  the wind speed,  $k$  the heat conductivity for air, and  $v$  the kinematic viscosity of air.  $K$  and  $n$  are empirically determined dimensionless constants (Kreith, 1965, p. 411). Appropriate values for  $K$  and  $n$  at  $V = 300 \text{ cm sec}^{-1}$  are given in Table I. Substituting Eq. (2) into Eq. (1) yields the wire diameter and wind speed dependence of  $\Delta T$ :

$$\Delta T = \left[ \epsilon_s \left( 1 + \frac{\pi\alpha}{2} \right) R_s + \pi \epsilon_L \left( \frac{R_a + R_g}{2} - \sigma T^4 \right) \right] \frac{D}{Kk} \left( \frac{v}{V D} \right)^n \quad (3)$$

Representative values of the parameters in Eq. (3) for a copper-constantan thermocouple suspended above a dry, desert surface at noon on a clear summer day are  $\alpha = 0.25$  (Sellers, 1965, p. 21),  $\epsilon_s = 0.25$ ,  $\epsilon_L = 0.5$  (Handbook of Chem. and Phys.),  $R_a = 0.008 \text{ cal cm}^{-2} \text{ sec}^{-1}$  (Gates, 1965),  $R_g = 0.015 \text{ cal cm}^{-2} \text{ sec}^{-1}$ ,  $R_s = 0.022 \text{ cal cm}^{-2} \text{ sec}^{-1}$ ,  $T = 300\text{K}$ , and  $V = 300 \text{ cm sec}^{-1}$  (representative of average experimental conditions to be described later). Values of  $\Delta T$  calculated using these numbers are presented in Table I.

Table I. Comparison of Measured and Calculated Values of  $\Delta T$  and  $\tau$  and values of  $K$  and  $n$  for  $V = 300 \text{ cm sec}^{-1}$

D-Cm	K	n	$\Delta T - \text{C}$		$\tau - \text{sec}$	
			Calculated	Measured	Calculated	Measured
0.0025	0.821	0.385	0.24	0.30	0.014	0.028
0.0127	0.821	0.385	0.65	0.75	0.19	0.35
0.0508	0.615	0.466	1.4	1.3	1.85	1.7

Experimental measurements of  $\Delta T$  were obtained by recording outputs from 0.0508, 0.0127, and 0.0025 cm diameter thermocouples and comparing them to the temperature measured with a thermocouple mounted in an MRI<sup>1</sup> model 801 aspirated thermoshield. The 0.0127 and 0.0025 cm thermocouple junctions were welded using a technique described by Campbell et al. (1968), modified to produce small junctions. The largest thermocouple was welded using a commercially available thermocouple welder. It was assumed that the thermocouple inside the aspirated thermoshield measured true air temperature since the manufacturer specifies a radiant heating error of less than 0.1C. The thermocouples and an anemometer were located at a height of 8 m above a dry desert surface at White Sands Missile Range, New Mexico. Temperatures and wind speed were recorded at 1 sec intervals between 1045 and 1215 hrs Mountain Daylight Time (MDT) on 16 May 1969, a cloudless day. The one-second temperature readings were averaged over five-minute intervals and the five-minute means were plotted to show the effect of radiant heating on the mean temperature measured by the thermocouples (Fig. 1). The measured  $R_s$ , obtained using an Eppley pyrheliometer, was  $0.022 \text{ cal cm}^{-2} \text{ sec}^{-1}$  at noon.

From 1045 to 1115 hrs the thermocouples were shaded from direct sunlight by the mast. During this time the readings of the smallest thermocouple were about the same as those of the standard (Fig. 1). The larger thermocouples gave temperatures above the standard. Between 1115 and 1215 hrs all of the thermocouples were exposed to direct sunlight. During this time, all of the thermocouples gave readings above true air temperature. The average of the differences between the temperature measured by each of the unshielded thermocouples in bright sunlight and that measured by the standard is shown in Table I. The average experimental values of  $\Delta T$  agree quite well with the values calculated using Eq. (3).

The  $\Delta T$  for each of the five-minute means was plotted as a function of the mean wind speed for each five-minute period to show the effect of wind speed on  $\Delta T$  (Fig. 2). Over the range of wind speeds shown,  $\Delta T$  for the smallest thermocouple is quite insensitive to wind speed changes while  $\Delta T$  for the largest thermocouple shows a rather large dependence on wind speed.

#### Time Constant of Thermocouples

The temperature response of an infinite cylinder to a step change in temperature is given by (Kreith, 1965, p. 129)

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<sup>1</sup>Meteorology Research Inc., Altadena, California.

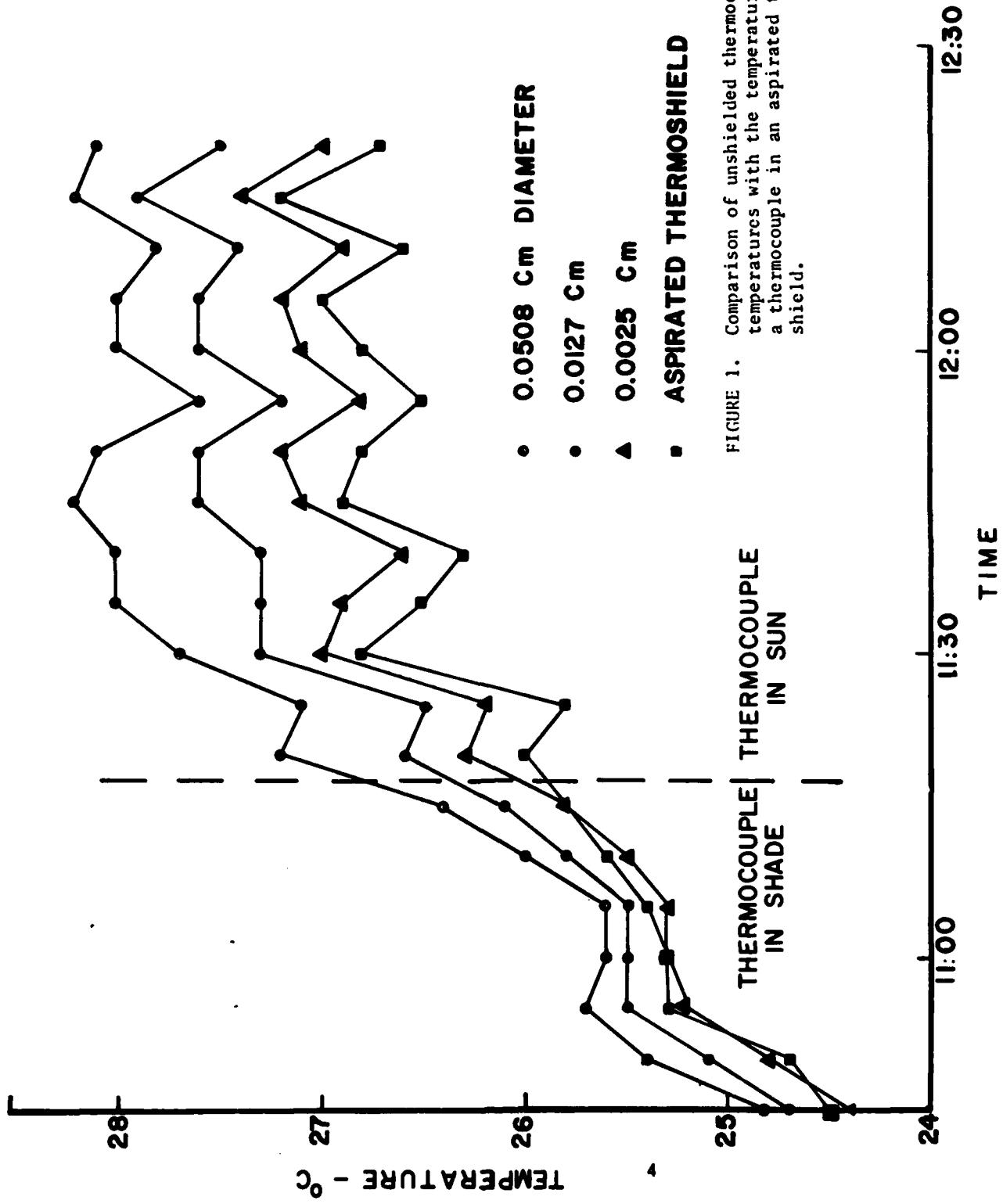


FIGURE 1. Comparison of unshielded thermocouple temperatures with the temperature of a thermocouple in an aspirated thermoshield.

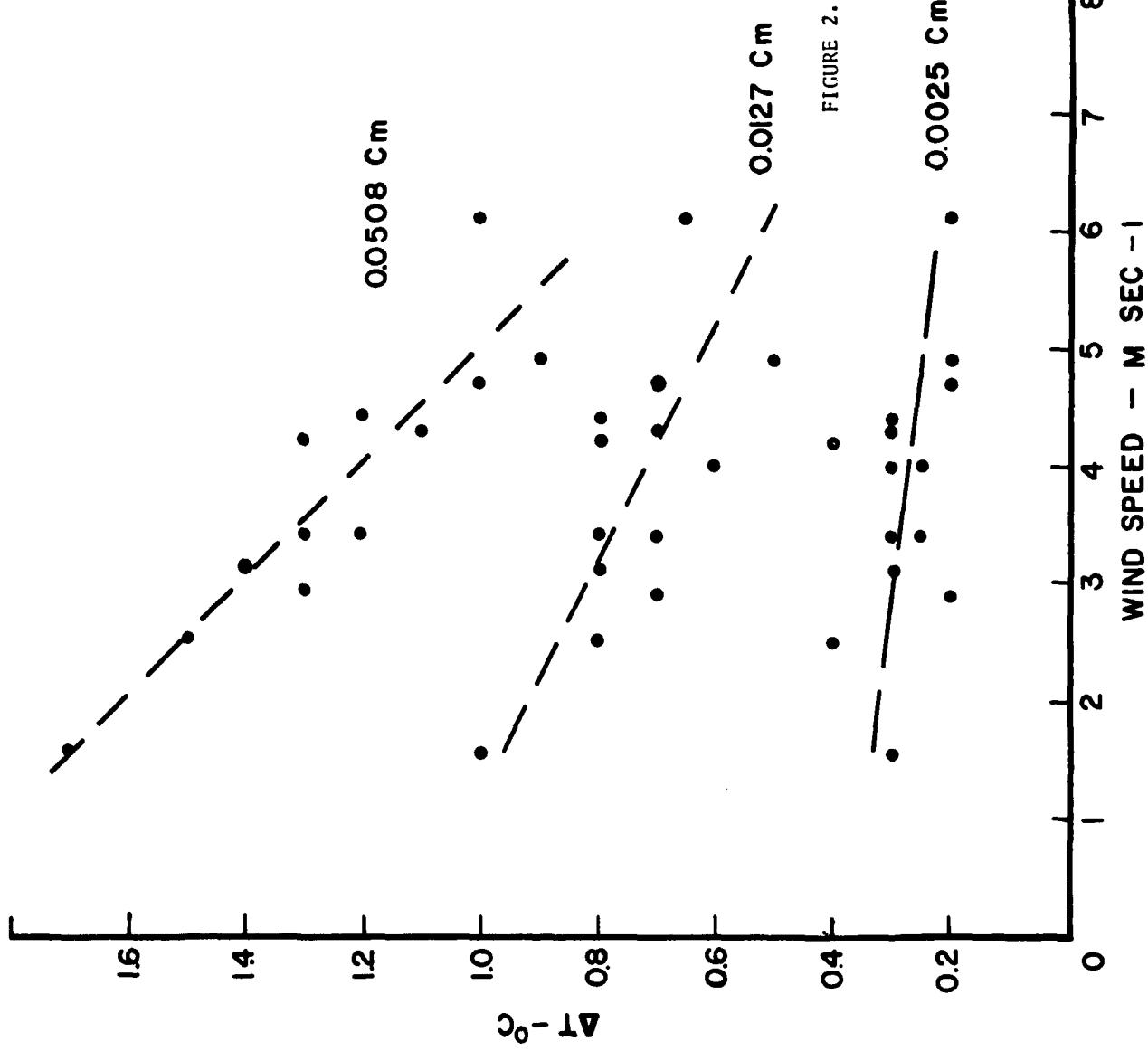


FIGURE 2. Effect of wind speed on radiant heating errors for three thermocouple sizes. Dashed curves are smoothed estimates of wind speed effects.

$$\frac{T - T_\infty}{T_0 - T_\infty} = \exp\left(-\frac{4h t}{c\rho D}\right) \quad (4)$$

where  $T_0$  and  $T_\infty$  are the initial thermocouple temperature and the air temperature,  $c$  and  $\rho$  the average heat capacity and density of the thermocouple material, respectively, and  $t$  is the time. The time constant of the thermocouple (Kreith, 1965, p. 129)

$$\tau = \frac{c\rho D}{4Kk}^2 \left( \frac{v}{V D} \right)^n \quad (5)$$

where  $h$  has been replaced from Eq. (2). Time constants calculated using Eq. (5) are shown in Table I. Values of  $\tau$  were measured by heating the thermocouples to 10-15°C above air temperature and recording their return to ambient temperature in a 300 cm sec<sup>-1</sup> artificial wind. The agreement between calculated and experimental values is good (Table I).

#### Measurements With Aspirated Thermocouples

Figure 1 shows that ambient temperatures measured with thermocouples are likely to be affected by direct solar radiation unless the thermocouples are mounted inside aspirated thermoshields. The next question was what effect does aspiration have on temperature fluctuation measurements. To investigate this, thermocouples made from 0.0025 diameter wire were mounted in a Climet<sup>2</sup> Model B2826 and an MRI Model 801 aspirated radiation shield, and measurements of temperature fluctuations were made at a height of 2 m above the ground. Time of day and location were the same as for the previous experiment. The 2 m height was used rather than 8 m to give more rapid fluctuations. The outputs from these aspirated thermocouples as well as the unshielded 0.0025 and 0.0127 cm diameter thermocouples at the same height were compared using a multichannel oscilloscope. The results are shown in Figure 3. Fluctuations measured by the thermocouple in the MRI shield closely resemble those measured with the smallest unshielded thermocouple. The trace for the larger unshielded thermocouple shows the filtering effect of the larger thermocouple mass, as expected.

The thermocouple in the Climet shield shows the same fluctuations but to a considerably reduced amplitude. The effect is attributed to mixing at the aspirator air intake because the amplitude reduction does not appear to depend on the frequency of the temperature fluctuations as is the case with filtering.

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<sup>2</sup>Climet Instruments Inc., Sunnyvale, California.

a. 0.0127 CM. UNASPIRATED



b. 0.0025 CM. MRI ASPIRATOR



c. 0.0025 CM. CLIMET ASPIRATOR



d. 0.0025 CM. UNASPIRATED



FIGURE 3. Comparison of temperature fluctuations measured with (a) 0.0127 cm unshielded thermocouple and with 0.0025 cm thermocouples in (b) an MRI aspirator, (c) a Climet aspirator, and (d) no thermoshield.

1°C

1 SEC

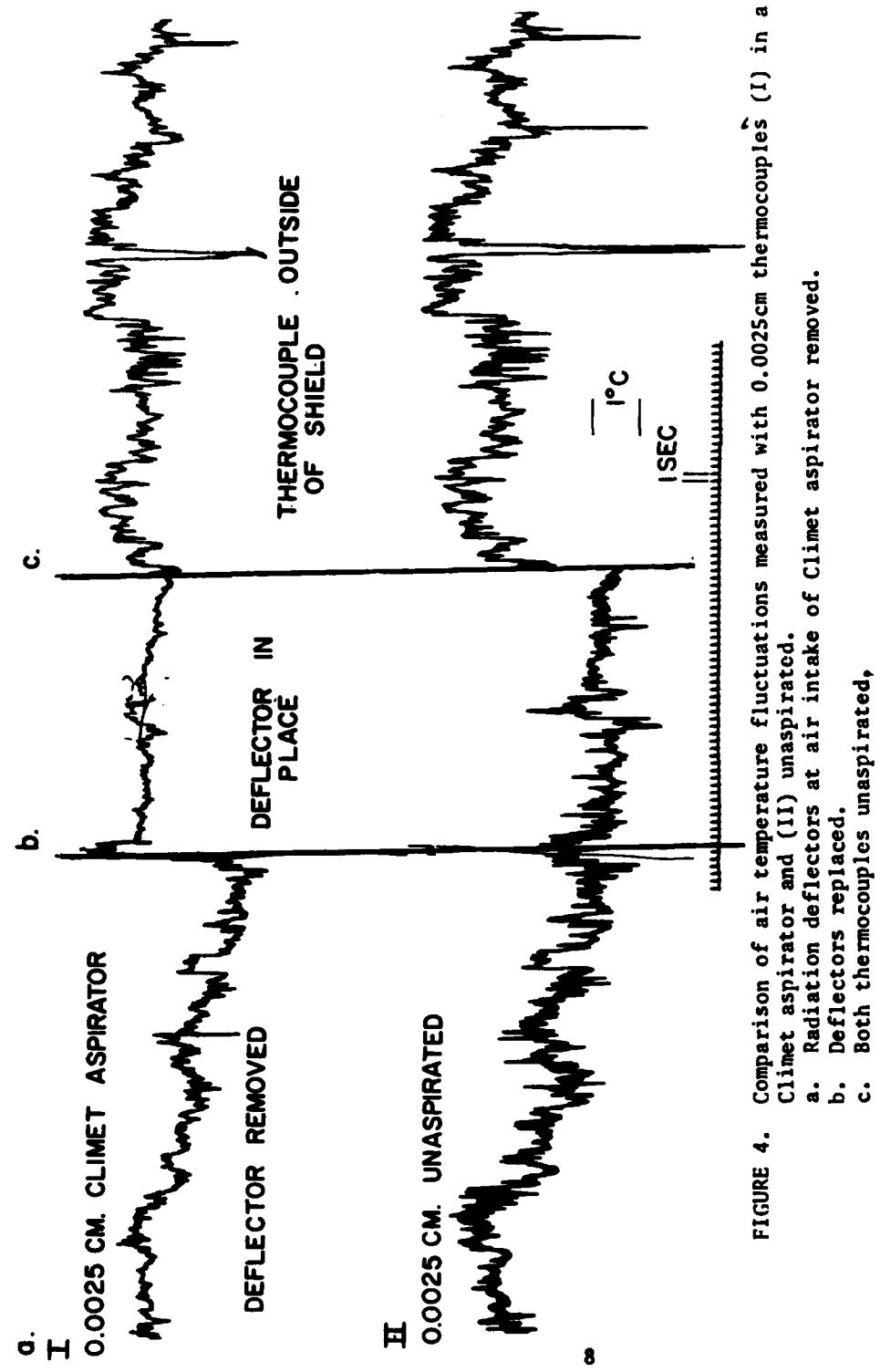


FIGURE 4. Comparison of air temperature fluctuations measured with 0.0025cm thermocouples (I) in a Climet aspirator and (II) un aspirated.

- Radiation deflectors at air intake of Climet aspirator removed.
- Deflectors replaced.
- Both thermocouples un aspirated,

An additional comparison of fluctuations measured by the thermocouple in the Climet aspirator with those measured by an unaspirated thermocouple is shown in Figure 4. Note that with the radiation deflector removed from the aspirator air intake (Fig. 4a) the fluctuations measured by the aspirated thermocouple compare favorably with those measured by the unaspirated thermocouple. The amplitude of the fluctuations is slightly smaller for the aspirated thermocouple, but it is also slightly smaller when the thermocouple is outside the shield and unaspirated (Fig. 4c). This difference may be due to slight differences between thermocouples or recorder channels. A marked difference is observed, however (Fig. 4b), when the deflector is replaced.

#### CONCLUSIONS

Based on the analysis presented, it appears that reasonable estimates of radiation heating and thermocouple time constant can be obtained from the heat transfer equations presented here. Significant radiant heating occurs even with very small thermocouples when they are exposed to direct sunlight. Small diameter thermocouples will provide reasonable air temperature estimates if shielded from direct solar radiation. The design of aspirated radiation shields should be considered critical in determining the effect of the shield on measured temperature fluctuations.

#### REFERENCES

Campbell, G. S., J. W. Trull, and W. H. Gardner, 1968. "A Welding Technique for Peltier Thermocouple Psychrometers," Soil Sci. Soc. Am. Proc., 32: 887-888.

Gates, D. M., 1965. "Radiant Energy, its Receipt and Disposal," Meteor. Monographs, 6 (28): 1-26.

House, G. J., N. E. Rider, and C. P. Tugwell, 1960. "A Surface Energy Balance Computer," Quart. J. Roy. Meteor. Soc., 86: 215-231.

Kreith F., 1965. Principles of Heat Transfer. International Textbook Co., Scranton, Penn. 620 p.

Sellers, W. D., 1965. Physical Climatology. The University of Chicago Press, Chicago, 272 p.

Swinbank, W. C., 1951. "The Measurement of the Vertical Transfer of Heat and Water Vapor by Eddies in the Lower Atmosphere," J. Meteor., 8: 135-145.

## ATMOSPHERIC SCIENCES RESEARCH PAPERS

1. Webb, W.L., "Development of Droplet Size Distributions in the Atmosphere," June 1954.
2. Hansen, F. V., and H. Rachele, "Wind Structure Analysis and Forecasting Methods for Rockets," June 1954.
3. Webb, W. L., "Net Electrification of Water Droplets at the Earth's Surface," *J. Meteorol.*, December 1954.
4. Mitchell, R., "The Determination of Non-Ballistic Projectile Trajectories," March 1955.
5. Webb, W. L., and A. McPike, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," #1, March 1955.
6. Mitchell, R., and W. L. Webb, "Electromagnetic Radiation through the Atmosphere," #1, April 1955.
7. Webb, W. L., A. McPike, and H. Thompson, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," #2, July 1955.
8. Barichivich, A., "Meteorological Effects on the Refractive Index and Curvature of Microwaves in the Atmosphere," August 1955.
9. Webb, W. L., A. McPike and H. Thompson, "Sound Ranging Technique for Determining the Trajectory of Supersonic Missiles," #3, September 1955.
10. Mitchell, R., "Notes on the Theory of Longitudinal Wave Motion in the Atmosphere," February 1956.
11. Webb, W. L., "Particulate Counts in Natural Clouds," *J. Meteorol.*, April 1956.
12. Webb, W. L., "Wind Effect on the Aerobee," #1, May 1956.
13. Rachele, H., and L. Anderson, "Wind Effect on the Aerobee," #2, August 1956.
14. Beyers, N., "Electromagnetic Radiation through the Atmosphere," #2, January 1957.
15. Hansen, F. V., "Wind Effect on the Aerobee," #3, January 1957.
16. Kershner, J., and H. Bear, "Wind Effect on the Aerobee," #4, January 1957.
17. Hoidale, G., "Electromagnetic Radiation through the Atmosphere," #3, February 1957.
18. Querfeld, C. W., "The Index of Refraction of the Atmosphere for 2.2 Micron Radiation," March 1957.
19. White, Lloyd, "Wind Effect on the Aerobee," #5, March 1957.
20. Kershner, J. G., "Development of a Method for Forecasting Component Ballistic Wind," August 1957.
21. Layton, Ivan, "Atmospheric Particle Size Distribution," December 1957.
22. Rachele, Henry and W. H. Hatch, "Wind Effect on the Aerobee," #6, February 1958.
23. Beyers, N. J., "Electromagnetic Radiation through the Atmosphere," #4, March 1958.
24. Prosser, Shirley J., "Electromagnetic Radiation through the Atmosphere," #5, April 1958.
25. Armendariz, M., and P. H. Taft, "Double Theodolite Ballistic Wind Computations," June 1958.
26. Jenkins, K. R. and W. L. Webb, "Rocket Wind Measurements," June 1958.
27. Jenkins, K. R., "Measurement of High Altitude Winds with Loki," July 1958.
28. Hoidale, G., "Electromagnetic Propagation through the Atmosphere," #6, February 1959.
29. McLardie, M., R. Helvey, and L. Traylor, "Low-Level Wind Profile Prediction Techniques," #1, June 1959.
30. Lamberth, Roy, "Gustiness at White Sands Missile Range," #1, May 1959.
31. Beyers, N. J., B. Hinds, and G. Hoidale, "Electromagnetic Propagation through the Atmosphere," #7, June 1959.
32. Beyers, N. J., "Radar Refraction at Low Elevation Angles (U)," Proceedings of the Army Science Conference, June 1959.
33. White, L., O. W. Thiele and P. H. Taft, "Summary of Ballistic and Meteorological Support During IGY Operations at Fort Churchill, Canada," August 1959.
34. Hainline, D. A., "Drag Cord-Aerovane Equation Analysis for Computer Application," August 1959.
35. Hoidale, G. B., "Slope-Valley Wind at WSMR," October 1959.
36. Webb, W. L., and K. R. Jenkins, "High Altitude Wind Measurements," *J. Meteorol.*, 16, 5, October 1959.

37. White, Lloyd, "Wind Effect on the Aerobee," #9, October 1959.
38. Webb, W. L., J. W. Coffman, and G. Q. Clark, "A High Altitude Acoustic Sensing System," December 1959.
39. Webb, W. L., and K. R. Jenkins, "Application of Meteorological Rocket Systems," *J. Geophys. Res.*, 64, 11, November 1959.
40. Duncan, Louis, "Wind Effect on the Aerobee," #10, February 1960.
41. Helvey, R. A., "Low-Level Wind Profile Prediction Techniques," #2, February 1960.
42. Webb, W. L., and K. R. Jenkins, "Rocket Sounding of High-Altitude Parameters," *Proc. GM Rel. Symp.*, Dept. of Defense, February 1960.
43. Armendariz, M., and H. H. Monahan, "A Comparison Between the Double Theodolite and Single-Theodolite Wind Measuring Systems," April 1960.
44. Jenkins, K. R., and P. H. Taft, "Weather Elements in the Tularosa Basin," July 1960.
45. Beyers, N. J., "Preliminary Radar Performance Data on Passive Rocket-Borne Wind Sensors," *IRE TRANS. MIL ELECT.*, MIL-4, 2-3, April-July 1960.
46. Webb, W. L., and K. R. Jenkins, "Speed of Sound in the Stratosphere," June 1960.
47. Webb, W. L., K. R. Jenkins, and G. Q. Clark, "Rocket Sounding of High Atmosphere Meteorological Parameters," *IRE Trans. Mil. Elect.*, MIL-4, 2-3, April-July 1960.
48. Helvey, R. A., "Low-Level Wind Profile Prediction Techniques," #3, September 1960.
49. Beyers, N. J., and O. W. Thiele, "Meteorological Wind Sensors," August 1960.
50. Armijo, Larry, "Determination of Trajectories Using Range Data from Three Non-collinear Radar Stations," September 1960.
51. Carnes, Patsy Sue, "Temperature Variations in the First 200 Feet of the Atmosphere in an Arid Region," July 1961.
52. Springer, H. S., and R. O. Olsen, "Launch Noise Distribution of Nike-Zeus Missiles," July 1961.
53. Thielk, O. W., "Density and Pressure Profiles Derived from Meteorological Rocket Measurements," September 1961.
54. Diamond, M. and A. B. Gray, "Accuracy of Missile Sound Ranging," November 1961.
55. Lamberth, R. L. and D. R. Veith, "Variability of Surface Wind in Short Distances," #1, October 1961.
56. Swanson, R. N., "Low-Level Wind Measurements for Ballistic Missile Application," January 1962.
57. Lamberth, R. L. and J. H. Grace, "Gustiness at White Sands Missile Range," #2, January 1962.
58. Swanson, R. N. and M. M. Hoidale, "Low-Level Wind Profile Prediction Techniques," #4, January 1962.
59. Rachele, Henry, "Surface Wind Model for Unguided Rockets Using Spectrum and Cross Spectrum Techniques," January 1962.
60. Rachele, Henry, "Sound Propagation through a Windy Atmosphere," #2, February 1962.
61. Webb, W. L., and K. R. Jenkins, "Sonic Structure of the Mesosphere," *J. Acous. Soc. Amer.*, 34, 2, February 1962.
62. Tourin, M. H. and M. M. Hoidale, "Low-Level Turbulence Characteristics at White Sands Missile Range," April 1962.
63. Miers, Bruce T., "Mesospheric Wind Reversal over White Sands Missile Range," March 1962.
64. Fisher, E., K. Lee and H. Rachele, "Meteorological Effects on an Acoustic Wave within a Sound Ranging Array," May 1962.
65. Walter, E. L., "Six Variable Ballistic Model for a Rocket," June 1962.
66. Webb, W. L., "Detailed Acoustic Structure Above the Tropopause," *J. Applied Meteorol.*, 1, 2, June 1962.
67. Jenkins, K. R., "Empirical Comparisons of Meteorological Rocket Wind Sensors," *J. Appl. Meteor.*, June 1962.
68. Lamberth, Roy, "Wind Variability Estimates as a Function of Sampling Interval," July 1962.
69. Rachele, Henry, "Surface Wind Sampling Periods for Unguided Rocket Impact Prediction," July 1962.
70. Traylor, Larry, "Coriolis Effects on the Aerobee-Hi Sounding Rocket," August 1962.
71. McCoy, J., and G. Q. Clark, "Meteorological Rocket Thermometry," August 1962.
72. Rachele, Henry, "Real-Time Prelaunch Impact Prediction System," August 1962.

73. Beyers, N. J., O. W. Thiele, and N. K. Wagner, "Performance Characteristics of Meteorological Rocket Wind and Temperature Sensors," October 1962.
74. Coffman, J., and R. Price, "Some Errors Associated with Acoustical Wind Measurements through a Layer," October 1962.
75. Armendariz, M., E. Fisher, and J. Serna, "Wind Shear in the Jet Stream at WS-MR," November 1962.
76. Armendariz, M., F. Hansen, and S. Carnes, "Wind Variability and its Effect on Rocket Impact Prediction," January 1963.
77. Querfeld, C., and Wayne Yunker, "Pure Rotational Spectrum of Water Vapor, I: Table of Line Parameters," February 1963.
78. Webb, W. L., "Acoustic Component of Turbulence," *J. Applied Meteorol.*, 2, 2, April 1963.
79. Beyers, N. and L. Engberg, "Seasonal Variability in the Upper Atmosphere," May 1963.
80. Williamson, L. E., "Atmospheric Acoustic Structure of the Sub-polar Fall," May 1963.
81. Lamberth, Roy and D. Veith, "Upper Wind Correlations in Southwestern United States," June 1963.
82. Sandlin, E., "An analysis of Wind Shear Differences as Measured by AN/FPS-16 Radar and AN/GMD-1B Rawinsonde," August 1963.
83. Diamond, M. and R. P. Lee, "Statistical Data on Atmospheric Design Properties Above 30 km," August 1963.
84. Thiele, O. W., "Mesospheric Density Variability Based on Recent Meteorological Rocket Measurements," *J. Applied Meteorol.*, 2, 5, October 1963.
85. Diamond, M., and O. Essenwanger, "Statistical Data on Atmospheric Design Properties to 30 km," *Astro. Aero. Engr.*, December 1963.
86. Hansen, F. V., "Turbulence Characteristics of the First 62 Meters of the Atmosphere," December 1963.
87. Morris, J. E., and B. T. Miers, "Circulation Disturbances Between 25 and 70 kilometers Associated with the Sudden Warming of 1963," *J. of Geophys. Res.*, January 1964.
88. Thiele, O. W., "Some Observed Short Term and Diurnal Variations of Stratospheric Density Above 30 km," January 1964.
89. Sandlin, R. E., Jr. and E. Armijo, "An Analysis of AN/FPS-16 Radar and AN/GMD-1B Rawinsonde Data Differences," January 1964.
90. Miers, B. T., and N. J. Beyers, "Rocketsonde Wind and Temperature Measurements Between 30 and 70 km for Selected Stations," *J. Applied Meteorol.*, February 1964.
91. Webb, W. L., "The Dynamic Stratosphere," *Astronautics and Aerospace Engineering*, March 1964.
92. Low, R. D. H., "Acoustic Measurements of Wind through a Layer," March 1964.
93. Diamond, M., "Cross Wind Effect on Sound Propagation," *J. Applied Meteorol.*, April 1964.
94. Lee, R. P., "Acoustic Ray Tracing," April 1964.
95. Reynolds, R. D., "Investigation of the Effect of Lapse Rate on Balloon Ascent Rate," May 1964.
96. Webb, W. L., "Scale of Stratospheric Detail Structure," *Space Research V*, May 1964.
97. Barber, T. L., "Proposed X-Ray-Infrared Method for Identification of Atmospheric Mineral Dust," June 1964.
98. Thiele, O. W., "Ballistic Procedures for Unguided Rocket Studies of Nuclear Environments (U)," Proceedings of the Army Science Conference, June 1964.
99. Horn, J. D., and E. J. Trawle, "Orographic Effects on Wind Variability," July 1964.
100. Hoidal, G., C. Querfeld, T. Hall, and R. Mireles, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," #1, September 1964.
101. Duncan, L. D., R. Ensey, and B. Engebos, "Athena Launch Angle Determination," September 1964.
102. Thiele, O. W., "Feasibility Experiment for Measuring Atmospheric Density Through the Altitude Range of 60 to 100 KM Over White Sands Missile Range," October 1964.
103. Duncan, L. D., and R. Ensey, "Six-Degree-of-Freedom Digital Simulation Model for Unguided, Fin-Stabilized Rockets," November 1964.

104. Hoidale, G., C. Querfeld, T. Hall, and R. Mireles, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," #2, November 1964.
105. Webb, W. L., "Stratospheric Solar Response," *J. Atmos. Sci.*, November 1964.
106. McCoy, J. and G. Clark, "Rocketsonde Measurement of Stratospheric Temperature," December 1964.
107. Farone, W. A., "Electromagnetic Scattering from Radially Inhomogeneous Spheres as Applied to the Problem of Clear Atmosphere Radar Echoes," December 1964.
108. Farone, W. A., "The Effect of the Solid Angle of Illumination or Observation on the Color Spectra of 'White Light' Scattered by Cylinders," January 1965.
109. Williamson, L. E., "Seasonal and Regional Characteristics of Acoustic Atmospheres," *J. Geophys. Res.*, January 1965.
110. Armendariz, M., "Ballistic Wind Variability at Green River, Utah," January 1965.
111. Low, R. D. H., "Sound Speed Variability Due to Atmospheric Composition," January 1965.
112. Querfeld, C. W., "Mie Atmospheric Optics," *J. Opt. Soc. Amer.*, January 1965.
113. Coffman, J., "A Measurement of the Effect of Atmospheric Turbulence on the Coherent Properties of a Sound Wave," January 1965.
114. Rachele, H., and D. Veith, "Surface Wind Sampling for Unguided Rocket Impact Prediction," January 1965.
115. Ballard, H., and M. Izquierdo, "Reduction of Microphone Wind Noise by the Generation of a Proper Turbulent Flow," February 1965.
116. Mireles, R., "An Algorithm for Computing Half Widths of Overlapping Lines on Experimental Spectra," February 1965.
117. Richart, H., "Inaccuracies of the Single-Theodolite Wind Measuring System in Ballistic Application," February 1965.
118. D'Arcy, M., "Theoretical and Practical Study of Aerobee-150 Ballistics," March 1965.
119. McCoy, J., "Improved Method for the Reduction of Rocketsonde Temperature Data," March 1965.
120. Mireles, R., "Uniqueness Theorem in Inverse Electromagnetic Cylindrical Scattering," April 1965.
121. Coffman, J., "The Focusing of Sound Propagating Vertically in a Horizontally Stratified Medium," April 1965.
122. Farone, W. A., and C. Querfeld, "Electromagnetic Scattering from an Infinite Circular Cylinder at Oblique Incidence," April 1965.
123. Rachele, H., "Sound Propagation through a Windy Atmosphere," April 1965.
124. Miers, B., "Upper Stratospheric Circulation over Ascension Island," April 1965.
125. Rider, L., and M. Armendariz, "A Comparison of Pibal and Tower Wind Measurements," April 1965.
126. Hoidale, G. B., "Meteorological Conditions Allowing a Rare Observation of 24 Micron Solar Radiation Near Sea Level," *Meteorol. Magazine*, May 1965.
127. Beyers, N. J., and B. T. Miers, "Diurnal Temperature Change in the Atmosphere Between 30 and 60 km over White Sands Missile Range," *J. Atmos. Sci.*, May 1965.
128. Querfeld, C., and W. A. Farone, "Tables of the Mie Forward Lobe," May 1965.
129. Farone, W. A., "Generalization of Rayleigh-Gans Scattering from Radially Inhomogeneous Spheres," *J. Opt. Soc. Amer.*, June 1965.
130. Diamond, M., "Note on Mesospheric Winds Above White Sands Missile Range," *J. Applied Meteorol.*, June 1965.
131. Clark, G. Q., and J. G. McCoy, "Measurement of Stratospheric Temperature," *J. Applied Meteorol.*, June 1965.
132. Hall, T., G. Hoidale, R. Mireles, and C. Querfeld, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," #3, July 1965.
133. McCoy, J., and C. Tate, "The Delta-T Meteorological Rocket Payload," June 1964.
134. Horn, J. D., "Obstacle Influence in a Wind Tunnel," July 1965.
135. McCoy, J., "An AC Probe for the Measurement of Electron Density and Collision Frequency in the Lower Ionosphere," July 1965.
136. Miers, B. T., M. D. Kays, O. W. Thiele and E. M. Newby, "Investigation of Short Term Variations of Several Atmospheric Parameters Above 30 KM," July 1965.

137. Serna, J., "An Acoustic Ray Tracing Method for Digital Computation," September 1965.
138. Webb, W. L., "Morphology of Noctilucent Clouds," *J. Geophys. Res.*, 70, 18, 4463-4475, September 1965.
139. Kays, M., and R. A. Craig, "On the Order of Magnitude of Large-Scale Vertical Motions in the Upper Stratosphere," *J. Geophys. Res.*, 70, 18, 4453-4462, September 1965.
140. Rider, L., "Low-Level Jet at White Sands Missile Range," September 1965.
141. Lamberth, R. L., R. Reynolds, and Morton Wurtele, "The Mountain Lee Wave at White Sands Missile Range," *Bull. Amer. Meteorol. Soc.*, 46, 10, October 1965.
142. Reynolds, R. and R. L. Lamberth, "Ambient Temperature Measurements from Radiosondes Flown on Constant-Level Balloons," October 1965.
143. McCluney, E., "Theoretical Trajectory Performance of the Five-Inch Gun Probe System," October 1965.
144. Pena, R. and M. Diamond, "Atmospheric Sound Propagation near the Earth's Surface," October 1965.
145. Mason, J. B., "A Study of the Feasibility of Using Radar Chaff For Stratospheric Temperature Measurements," November 1965.
146. Diamond, M., and R. P. Lee, "Long-Range Atmospheric Sound Propagation," *J. Geophys. Res.*, 70, 22, November 1965.
147. Lamberth, R. L., "On the Measurement of Dust Devil Parameters," November 1965.
148. Hansen, F. V., and P. S. Hansen, "Formation of an Internal Boundary over Heterogeneous Terrain," November 1965.
149. Webb, W. L., "Mechanics of Stratospheric Seasonal Reversals," November 1965.
150. U. S. Army Electronics R & D Activity, "U. S. Army Participation in the Meteorological Rocket Network," January 1966.
151. Rider, L. J., and M. Armendariz, "Low-Level Jet Winds at Green River, Utah," February 1966.
152. Webb, W. L., "Diurnal Variations in the Stratospheric Circulation," February 1966.
153. Beyers, N. J., B. T. Miers, and R. J. Reed, "Diurnal Tidal Motions near the Strato-pause During 48 Hours at WSMR," February 1966.
154. Webb, W. L., "The Stratospheric Tidal Jet," February 1966.
155. Hall, J. T., "Focal Properties of a Plane Grating in a Convergent Beam," February 1966.
156. Duncan, L. D., and Henry Rachele, "Real-Time Meteorological System for Firing of Unguided Rockets," February 1966.
157. Kays, M. D., "A Note on the Comparison of Rocket and Estimated Geostrophic Winds at the 10-mb Level," *J. Appl. Meteor.*, February 1966.
158. Rider, L., and M. Armendariz, "A Comparison of Pibal and Tower Wind Measurements," *J. Appl. Meteor.*, 5, February 1966.
159. Duncan, L. D., "Coordinate Transformations in Trajectory Simulations," February 1966.
160. Williamson, L. E., "Gun-Launched Vertical Probes at White Sands Missile Range," February 1966.
161. Randhawa, J. S., "Ozone Measurements with Rocket-Borne Ozonesondes," March 1966.
162. Armendariz, Manuel, and Laurence J. Rider, "Wind Shear for Small Thickness Layers," March 1966.
163. Low, R. D. H., "Continuous Determination of the Average Sound Velocity over an Arbitrary Path," March 1966.
164. Hansen, Frank V., "Richardson Number Tables for the Surface Boundary Layer," March 1966.
165. Cochran, V. C., E. M. D'Arcy, and Florencio Ramirez, "Digital Computer Program for Five-Degree-of-Freedom Trajectory," March 1966.
166. Thiele, O. W., and N. J. Beyers, "Comparison of Rocketsonde and Radiosonde Temperatures and a Verification of Computed Rocketsonde Pressure and Density," April 1966.
167. Thiele, O. W., "Observed Diurnal Oscillations of Pressure and Density in the Upper Stratosphere and Lower Mesosphere," April 1966.
168. Kays, M. D., and R. A. Craig, "On the Order of Magnitude of Large-Scale Vertical Motions in the Upper Stratosphere," *J. Geophys. Res.*, April 1966.
169. Hansen, F. V., "The Richardson Number in the Planetary Boundary Layer," May 1966.

170. Ballard, H. N., "The Measurement of Temperature in the Stratosphere and Mesosphere," June 1966.
171. Hansen, Frank V., "The Ratio of the Exchange Coefficients for Heat and Momentum in a Homogeneous, Thermally Stratified Atmosphere," June 1966.
172. Hansen, Frank V., "Comparison of Nine Profile Models for the Diabatic Boundary Layer," June 1966.
173. Rachele, Henry, "A Sound-Ranging Technique for Locating Supersonic Missiles," May 1966.
174. Farone, W. A., and C. W. Querfeld, "Electromagnetic Scattering from Inhomogeneous Infinite Cylinders at Oblique Incidence," *J. Opt. Soc. Amer.* 56, 4, 476-480, April 1966.
175. Mireles, Ramon, "Determination of Parameters in Absorption Spectra by Numerical Minimization Techniques," *J. Opt. Soc. Amer.* 56, 5, 644-647, May 1966.
176. Reynolds, R., and R. L. Lamberth, "Ambient Temperature Measurements from Radiosondes Flown on Constant-Level Balloons," *J. Appl. Meteorol.*, 5, 3, 304-307, June 1966.
177. Hall, James T., "Focal Properties of a Plane Grating in a Convergent Beam," *Appl. Opt.*, 5, 1051, June 1966
178. Rider, Laurence J., "Low-Level Jet at White Sands Missile Range," *J. Appl. Meteorol.*, 5, 3, 283-287, June 1966.
179. McCluney, Eugene, "Projectile Dispersion as Caused by Barrel Displacement in the 5-Inch Gun Probe System," July 1966.
180. Armendariz, Manuel, and Laurence J. Rider, "Wind Shear Calculations for Small Shear Layers," June 1966.
181. Lamberth, Roy L., and Manuel Armendariz, "Upper Wind Correlations in the Central Rocky Mountains," June 1966.
182. Hansen, Frank V., and Virgil D. Lang, "The Wind Regime in the First 62 Meters of the Atmosphere," June 1966.
183. Randhawa, Jagir S., "Rocket-Borne Ozonesonde," July 1966.
184. Rachele, Henry, and L. D. Duncan, "The Desirability of Using a Fast Sampling Rate for Computing Wind Velocity from Pilot-Balloon Data," July 1966.
185. Hinds, B. D., and R. G. Pappas, "A Comparison of Three Methods for the Correction of Radar Elevation Angle Refraction Errors," August 1966.
186. Riedmuller, G. F., and T. L. Barber, "A Mineral Transition in Atmospheric Dust Transport," August 1966.
187. Hall, J. T., C. W. Querfeld, and G. B. Hoidale, "Spectral Transmissivity of the Earth's Atmosphere in the 250 to 500 Wave Number Interval," Part IV (Final), July 1966.
188. Duncan, L. D. and B. F. Engebos, "Techniques for Computing Launcher Settings for Unguided Rockets," September 1966.
189. Duncan, L. D., "Basic Considerations in the Development of an Unguided Rocket Trajectory Simulation Model," September 1966.
190. Miller, Walter B., "Consideration of Some Problems in Curve Fitting," September 1966.
191. Cermak, J. E., and J. D. Horn, "The Tower Shadow Effect," August 1966.
192. Webb, W. L., "Stratospheric Circulation Response to a Solar Eclipse," October 1966.
193. Kennedy, Bruce, "Muzzle Velocity Measurement," October 1966.
194. Traylor, Larry E., "A Refinement Technique for Unguided Rocket Drag Coefficients," October 1966
195. Nusbaum, Henry, "A Reagent for the Simultaneous Microscope Determination of Quartz and Halides," October 1966.
196. Kays, Marvin and R. O. Olsen, "Improved Rocketsonde Parachute-derived Wind Profiles," October 1966.
197. Engebos, Bernard F. and Duncan, Louis D., "A Nomogram for Field Determination of Launcher Angles for Unguided Rockets," October 1966.
198. Webb, W. L., "Midlatitude Clouds in the Upper Atmosphere," November 1966.
199. Hansen, Frank V., "The Lateral Intensity of Turbulence as a Function of Stability," November 1966.
200. Rider, L. J. and M. Armendariz, "Differences of Tower and Pibal Wind Profiles," November 1966.
201. Lee, Robert P., "A Comparison of Eight Mathematical Models for Atmospheric Acoustical Ray Tracing," November 1966.
202. Low, R. D. H., et al., "Acoustical and Meteorological Data Report SOTRAN I and II," November 1966.

203. Hunt, J. A. and J. D. Horn, "Drag Plate Balance," December 1966.
204. Armendariz, M., and H. Rachele, "Determination of a Representative Wind Profile from Balloon Data," December 1966.
205. Hansen, Frank V., "The Aerodynamic Roughness of the Complex Terrain of White Sands Missile Range," January 1967.
206. Morris, James E., "Wind Measurements in the Subpolar Mesopause Region," January 1967.
207. Hall, James T., "Attenuation of Millimeter Wavelength Radiation by Gaseous Water," January 1967.
208. Thiele, O. W., and N. J. Beyers, "Upper Atmosphere Pressure Measurements With Thermal Conductivity Gauges," January 1967.
209. Armendariz, M., and H. Rachele, "Determination of a Representative Wind Profile from Balloon Data," January 1967.
210. Hansen, F. V., "The Aerodynamic Roughness of the Complex Terrain of White Sands Missile Range, New Mexico," January 1967.
211. D'Arcy, Edward M., "Some Applications of Wind to Unguided Rocket Impact Prediction," March 1967.
212. Kennedy, Bruce, "Operation Manual for Stratosphere Temperature Sonde," March 1967.
213. Hoidale, G. B., S. M. Smith, A. J. Blanco, and T. L. Barber, "A Study of Atmospheric Dust," March 1967.
214. Longyear, J. Q., "An Algorithm for Obtaining Solutions to Laplace's Tidal Equations," March 1967.
215. Rider, L. J., "A Comparison of Pibal with Raob and Rawin Wind Measurements," April 1967.
216. Breeland, A. H., and R. S. Bonner, "Results of Tests Involving Hemispherical Wind Screens in the Reduction of Wind Noise," April 1967.
217. Webb, Willis L., and Max C. Bolen, "The D-region Fair-Weather Electric Field," April 1967.
218. Kubinski, Stanley F., "A Comparative Evaluation of the Automatic Tracking Pilot-Balloon Wind Measuring System," April 1967.
219. Miller, Walter B., and Henry Rachele, "On Nonparametric Testing of the Nature of Certain Time Series," April 1967.
220. Hansen, Frank V., "Spacial and Temporal Distribution of the Gradient Richardson Number in the Surface and Planetary Layers," May 1967.
221. Randhawa, Jagir S., "Diurnal Variation of Ozone at High Altitudes," May 1967.
222. Ballard, Harold N., "A Review of Seven Papers Concerning the Measurement of Temperature in the Stratosphere and Mesosphere," May 1967.
223. Williams, Ben H., "Synoptic Analyses of the Upper Stratospheric Circulation During the Late Winter Storm Period of 1966," May 1967.
224. Horn, J. D., and J. A. Hunt, "System Design for the Atmospheric Sciences Office Wind Research Facility," May 1967.
225. Miller, Walter B., and Henry Rachele, "Dynamic Evaluation of Radar and Photo Tracking Systems," May 1967.
226. Bonner, Robert S., and Ralph H. Rohwer, "Acoustical and Meteorological Data Report - SOTRAN III and IV," May 1967.
227. Rider, L. J., "On Time Variability of Wind at White Sands Missile Range, New Mexico," June 1967.
228. Randhawa, Jagir S., "Mesospheric Ozone Measurements During a Solar Eclipse," June 1967.
229. Beyers, N. J., and B. T. Miers, "A Tidal Experiment in the Equatorial Stratosphere over Ascension Island (8S)," June 1967.
230. Miller, W. B., and H. Rachele, "On the Behavior of Derivative Processes," June 1967
231. Walters, Randall K., "Numerical Integration Methods for Ballistic Rocket Trajectory Simulation Programs," June 1967.
232. Hansen, Frank V., "A Diabatic Surface Boundary Layer Model," July 1967.
233. Butler, Ralph L., and James K. Hall, "Comparison of Two Wind Measuring Systems with the Contraves Photo-Theodolite," July 1967.
234. Webb, Willis L., "The Source of Atmospheric Electrification," June 1967.

235. Hinds, B. D., "Radar Tracking Anomalies over an Arid Interior Basin," August 1967.
236. Christian, Larry O., "Radar Cross Sections for Totally Reflecting Spheres," August 1967.
237. D'Arcy, Edward M., "Theoretical Dispersion Analysis of the Aerobee 350," August 1967.
238. Anon., "Technical Data Package for Rocket-Borne Temperature Sensor," August 1967.
239. Glass, Roy I., Roy L. Lamberth, and Ralph D. Reynolds, "A High Resolution Continuous Pressure Sensor Modification for Radiosondes," August 1967.
240. Low, Richard D. H., "Acoustic Measurement of Supersaturation in a Warm Cloud," August 1967.
241. Rubio, Roberto, and Harold N. Ballard, "Time Response and Aerodynamic Heating of Atmospheric Temperature Sensing Elements," August 1967.
242. Seagraves, Mary Ann B., "Theoretical Performance Characteristics and Wind Effects for the Aerobee 150," August 1967.
243. Duncan, Louis Dean, "Channel Capacity and Coding," August 1967.
244. Dunaway, G. L., and Mary Ann B. Seagraves, "Launcher Settings Versus Jack Settings for Aerobee 150 Launchers - Launch Complex 35, White Sands Missile Range, New Mexico," August 1967.
245. Duncan, Louis D., and Bernard F. Engebos, "A Six-Degree-of-Freedom Digital Computer Program for Trajectory Simulation," October 1967.
246. Rider, Laurence J., and Manuel Armendariz, "A Comparison of Simultaneous Wind Profiles Derived from Smooth and Roughened Spheres," September 1967.
247. Reynolds, Ralph D., Roy L. Lamberth, and Morton G. Wurtele, "Mountain Wave Theory vs Field Test Measurements," September 1967.
248. Lee, Robert P., "Probabilistic Model for Acoustic Sound Ranging," October 1967.
249. Williamson, L. Edwin, and Bruce Kennedy, "Meteorological Shell for Standard Artillery Pieces - A Feasibility Study," October 1967.
250. Rohwer, Ralph H., "Acoustical, Meteorological and Seismic Data Report - SOTRAN V and VI," October 1967.
251. Nordquist, Walter S., Jr., "A Study in Acoustic Direction Finding," November 1967.
252. Nordquist, Walter S., Jr., "A Study of Acoustic Monitoring of the Gun Probe System," November 1967.
253. Avara, E. P., and B. T. Miers, "A Data Reduction Technique for Meteorological Wind Data above 30 Kilometers," December 1967.
254. Hansen, Frank V., "Predicting Diffusion of Atmospheric Contaminants by Consideration of Turbulent Characteristics of WSMR," January 1968.
255. Randhawa, Jagir S., "Rocket Measurements of Atmospheric Ozone," January 1968.
256. D'Arcy, Edward M., "Meteorological Requirements for the Aerobee-350," January 1968.
257. D'Arcy, Edward M., "A Computer Study of the Wind Frequency Response of Unguided Rockets," February 1968.
258. Williamson, L. Edwin, "Gun Launched Probes - Parachute Expulsion Tests Under Simulated Environment," February 1968.
259. Beyers, Norman J., Bruce T. Miers, and Elton P. Avara, "The Diurnal Tide Near the Stratopause over White Sands Missile Range, New Mexico," February 1968.
260. Traylor, Larry E., "Preliminary Study of the Wind Frequency Response of the Honest John M50 Tactical Rocket," March 1968.
261. Engebos, B. F., and L. D. Duncan, "Real-Time Computations of Pilot Balloon Winds," March 1968.
262. Butler, Ralph and L. D. Duncan, "Empirical Estimates of Errors in Double-Theodolite Wind Measurements," February 1968.
263. Kennedy, Bruce, et al., "Thin Film Temperature Sensor," March 1968.
264. Bruce, Dr. Rufus, James Mason, Dr. Kenneth White and Richard B. Gomez, "An Estimate of the Atmospheric Propagation Characteristics of 1.54 Micron Laser Energy," March 1968.

265. Ballard, Harold N., Jagir S. Randhawa, and Willis L. Webb, "Stratospheric Circulation Response to a Solar Eclipse," March 1968.
266. Johnson, James L., and Orville C. Kuberski, "Timing Controlled Pulse Generator," April 1968.
267. Blanco, Abel J., and Glenn B. Hoidal, "Infrared Absorption Spectra of Atmospheric Dust," May 1968.
268. Jacobs, Willie N., "Automatic Pibal Tracking System," May 1968.
269. Morris, James E., and Marvin D. Kays, "Circulation in the Arctic Mesosphere in Summer," June 1968.
270. Mason, James B., "Detection of Atmospheric Oxygen Using a Tuned Ruby Laser," June 1968.
271. Armendariz, Manuel, and Virgil D. Lang, "Wind Correlation and Variability in Time and Space," July 1968.
272. Webb, Willis L., "Tropospheric Electrical Structure," July 1968.
273. Miers, Bruce T., and Elton P. Avara, "Analysis of High-Frequency Components of AN/FPS-16 Radar Data," August 1968.
274. Dunaway, Gordon L., "A Practical Field Wind Compensation Technique for Unguided Rockets," August 1968.
275. Seagraves, Mary Ann B., and Barry Butler, "Performance Characteristics and Wind Effects for the Aerobee 150 with VAM Booster," September 1968.
276. Low, Richard D. H., "A Generalized Equation for Droplet Growth Due to the Solution Effect," September 1968.
277. Jenkins, Kenneth R., "Meteorological Research, Development, Test, and Evaluation Rocket," September 1968.
278. Williams, Ben H., and Bruce T. Miers, "The Synoptic Events of the Stratospheric Warming of December 1967 - January 1968," September 1968.
279. Tate, C. L., and Bruce W. Kennedy, "Technical Data Package for Atmospheric Temperature Sensor Mini-Loki," September 1968.
280. Rider, Laurence J., Manuel Armendariz, and Frank V. Hansen, "A Study of Wind and Temperature Variability at White Sands Missile Range, New Mexico," September 1968.
281. Duncan, Louis D., and Walter B. Miller, "The Hull of a Channel," September 1968.
282. Hansen, Frank V., and Gary A. Ethridge, "Diffusion Nomograms and Tables for Rocket Propellants and Combustion By-Products," January 1968.
283. Walters, Randall K., and Bernard F. Engebos, "An Improved Method of Error Control for Runge-Kutta Numerical Integration," October 1968.
284. Miller, Walter B., "A Non-Entropy Approach to Some Topics in Channel Theory," November 1968.
285. Armendariz, Manuel, Laurence J. Rider, and Frank V. Hansen, "Turbulent Characteristics in the Surface Boundary Layer," November 1968.
286. Randhawa, Jagir S., "Rocket Measurements of the Diurnal Variation of Atmospheric Ozone," December 1968.
287. Randhawa, Jagir S., "A Guide to Rocketsonde Measurements of Atmospheric Ozone," January 1969.
288. Webb, Willis L., "Solar Control of the Stratospheric Circulation," February 1969.
289. Lee, Robert P., "A Dimensional Analysis of the Errors of Atmospheric Sound Ranging," March 1969.
290. Barber, T. L., "Degradation of Laser Optical Surfaces," March 1969.
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13. ABSTRACT <p>Equations for determining the radiant heating and time constant of small thermocouples used for air temperature measurement are presented. Calculated and measured values are compared for 0.0025, 0.0127, and 0.0508 cm diameter copper-constantan thermocouples exposed to direct sunlight. The largest thermocouple gives measured temperatures that are approximately 1.3C higher than air temperature, and the smallest thermocouple reads about 0.3C above air temperature when they are exposed to direct solar radiation. In direct sunlight and for a range of wind speed of 100 to 500 cm sec<sup>-1</sup> the temperature is reduced by 0.8 and 0.1C for the largest and smallest thermocouples, respectively.</p> <p>The effects of two types of aspirated thermoshields on temperature fluctuations measured inside the shield with the 0.0025 cm thermocouples were determined. Thermoshield design was shown to be critical in temperature fluctuation measurement.</p>		

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